K. J. Somaiya College of Engineering, Mumbai-77
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Design and Analysis of the Drive Train of an All-Terrain Vehicle

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Project Guide: Prof. V S Narwane

Introduction

Our project includes the design, analysis and manufacture of the entire Drive train system of an all-terrain vehicle, in association with RedShift Racing India, which participates in BAJA competitions.

- **Objective of Project:**

1. Design and analysis of components including the gears, rear axle, housing, etc.
2. Study of performance characteristics of the CVT and parameters that determine them. Study of CVT tuning and implementation.
3. Study of Vibrational analysis of an engine. Experimental analysis of the current engine and suitable damping and mounting of the engine.

- **Goals of Project:**

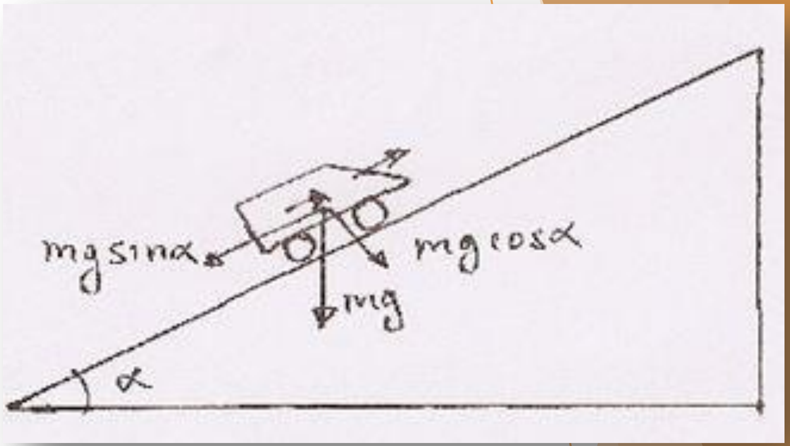
1. Design a smooth and efficient transmission system to successfully complete the Hill Climb, Traction and Endurance Event.
2. Provide maximum acceleration through CVT Tuning.
3. Design and optimize transmission system to match and compete with current ATV systems.

Design of the Gearbox

1. Determination of the reduction ratio.
2. Selecting the materials.
3. Calculating the modules of each stage.
4. Gear, shaft and key dimensions.
5. Selecting the bearings.
6. Designing the casing.
7. Analysis of the components.
8. Assembly.
9. Drafting and tolerances.

Determination of the reduction ratio:

Steps	Outcomes
Calculation for maximum angle of inclination.	34.999 degrees
Calculation for required torque.	551.81 Nm
Calculation for total drive train reduction ratio	41.385 to 43.56
Calculation for gearbox reduction ratio	13.79 to 14.52
Selecting no. of teeth	Pinion 17. Gear 64 Actual Ratio 14.167



Selecting the materials:

Material	Yield Strength (N/mm^2)	BHN
EN 24 (1st stage reduction)	700	280
EN 36 (2nd stage reduction)	900	341

- <u>Calculating the modules of each stage:</u>

1. Helix angle selected – 15 degrees
2. FOS considered – 2
3. Module selection equation - Lewis Equation
4. Bending strength (Fs) = Sb x b x y_v x π x m_n
5. Wear strength (Fw) = (b x d x Q x k)/$\cos^2$(b)

Aspect	Pinion 1	Gear 1	Pinion 2	Gear 2
Number of teeth	17	64	17	64
Material	EN 24	EN 24	EN 36	EN 36
FOS	2	2	2	2
Module	2	2	3	3
P.C.D (mm)	35.1994	132.515	52.799	198.77
Addendum dia.	39.1994	136.1994	58.799	204.77
Dedendum dia	30.1994	127.515	45.299	191.27

- Gear, shaft and key dimensions:

1. Torque at input (T) = P x 60 / 2 x π x N
2. Bending moment, we take T_{eq} = 1.5 x T
3. Allowable sheer stress (Ss) = 0.3 x Sy
4. From torsion equation, we get $d^3 = (16 \times T_{eq})/(\pi \times Ss)$

- Selecting the bearings: 32005 X/Q, 32007 X/Q (SKF)

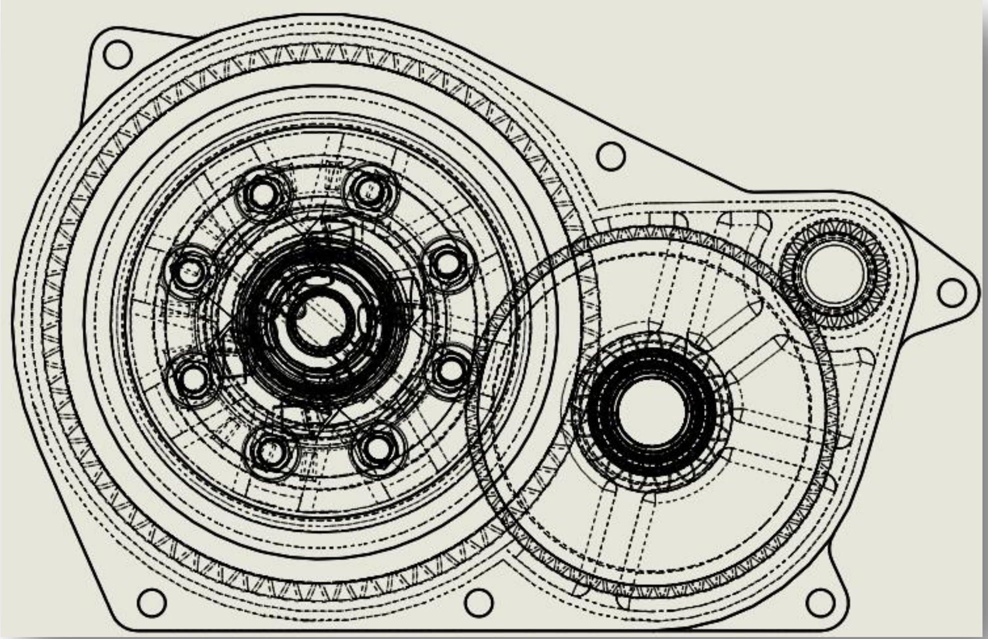
- Designing the casing:

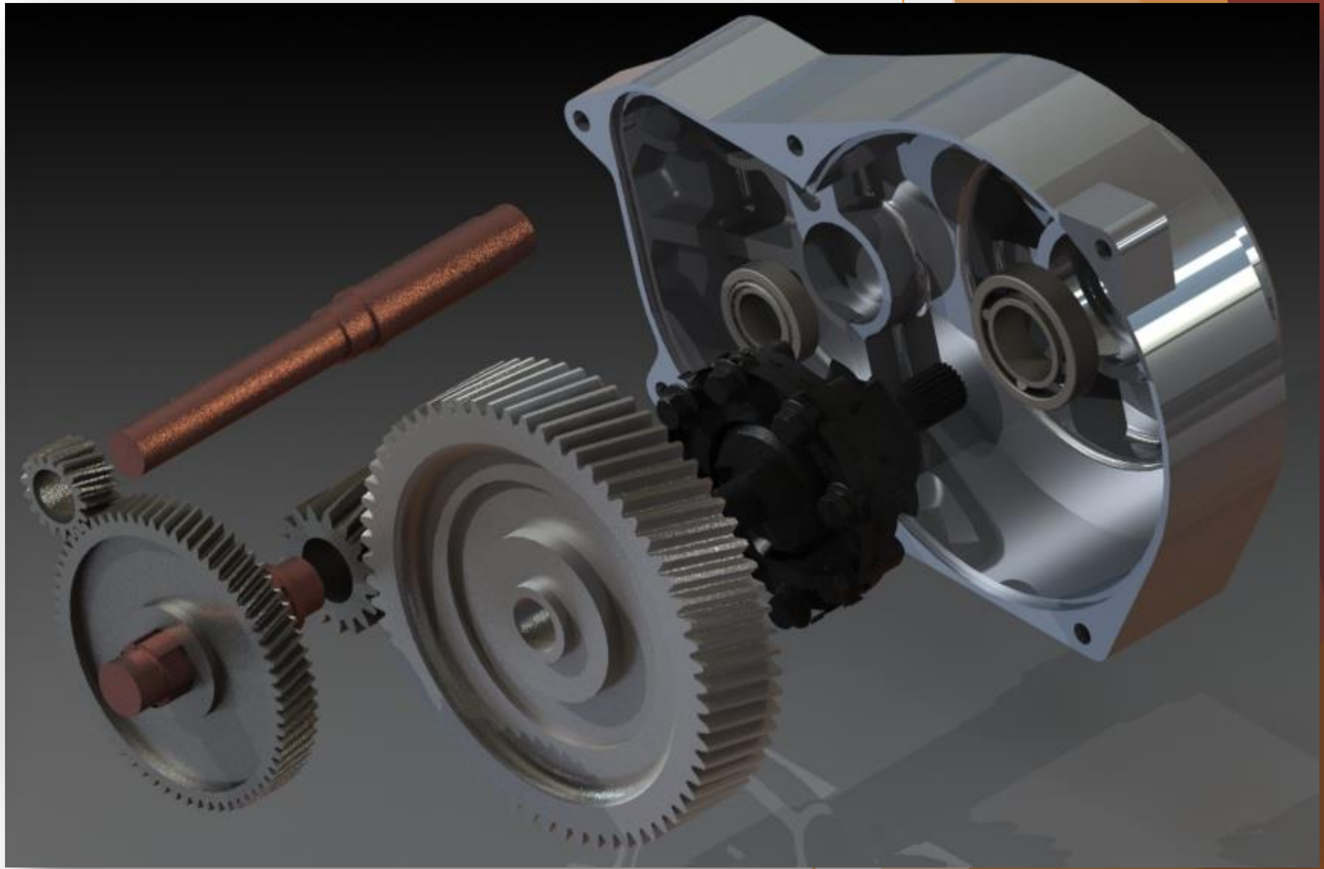
1. Material selected – LM6 (Aluminum Alloy)

   Tensile Strength – 170 N/mm^2

   Shear Strength – 120 N/mm^2

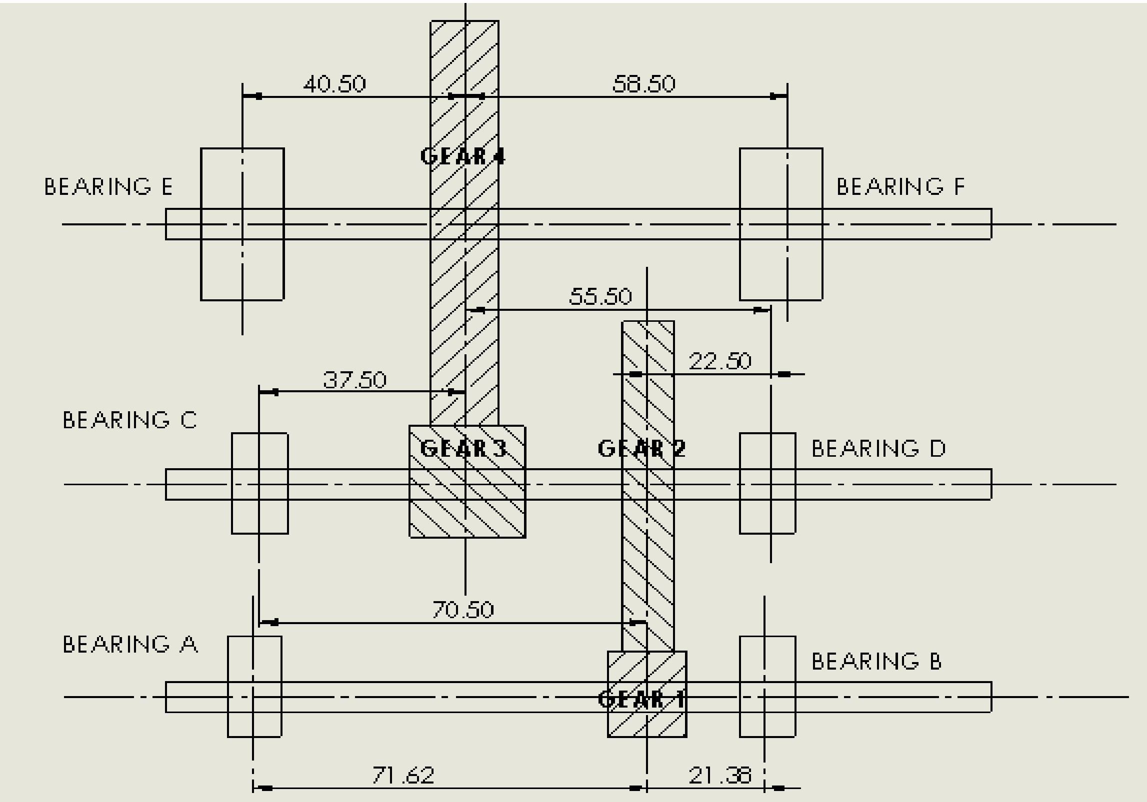
Design of the Gearbox





Gearbox Analysis

- For the analysis of the gearbox, we have used the structural workbench on ANSYS.
- The forces considered for the analysis of the gears are the tangential force components and the thrust components.
- The forces considered for the housing dimensions are the bearing reactions due to the forces on the gears.



Gearbox analysis

Steps for analysis:

1. Importing Geometry

Geometry	
Object Name	Gearbox
State	Fully Defined
Definition	
Length Unit	Millimeters
Element Control	Program Controlled
Bounding Box	
Length X	0.178 m
Length Y	0.33332 m

2. Assigning Material Properties

Material		
Assignment	Aluminum Alloy LM 6 Series	
Properties		
Volume	1.2939e-003 m³	9.5056e-004 m³
Mass	3.4288 kg	2.519 kg

Density	2650 kg m^-3
Coefficient of Thermal Expansion	2.e-005 C^-1
Specific Heat	875 J kg^-1 C^-1

Young's Modulus Pa	7.1e+010
Poisson's Ratio	0.33
Bulk Modulus Pa	6.9608e+010
Shear Modulus Pa	2.6692e+010
Compressive Yield Strength Pa	1.7e+008
Tensile Ultimate Strength Pa	3.1e+008
Tensile Yield Strength Pa	1.7e+008

3. Meshing:

Object Name	*Gearbox Mesh*
State	Solved
Physics Preference	Mechanical
Sizing	
Element Size	1.e-003 m
Minimum Edge Length	1.7908e-004 m
Triangle Surface Mesh	Program Controlled
Advanced	
Shape Checking	Standard Mechanical
Element Mid-side Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Mesh Morphing	Disabled
Statistics	
Nodes	2056607
Elements	1252306

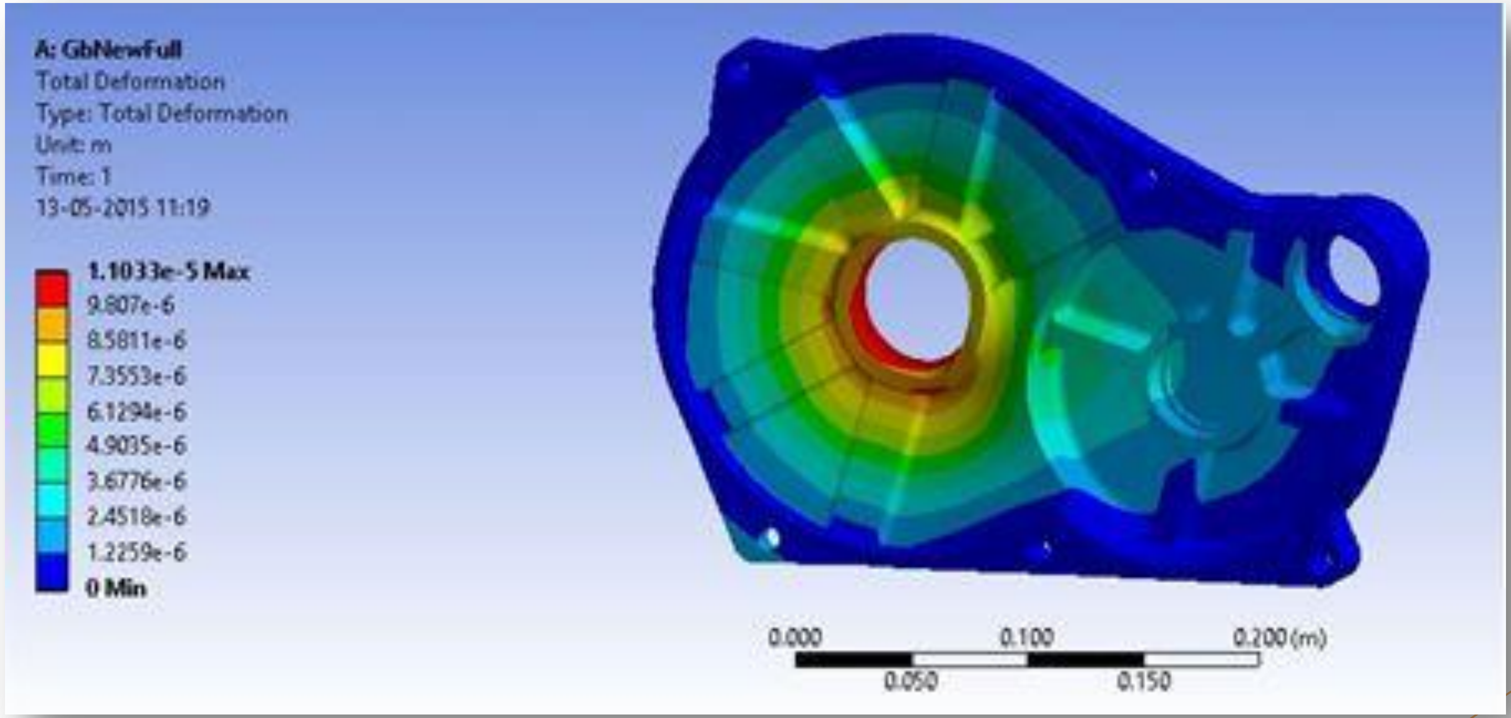
4. Applying Boundary Conditions:

1. All the mounting positions and bolting positions are fixed.
2. Axial thrust and radial forces are applied on bearing seats in proper directions.

Gearbox Analysis

- The table shows the analysis results for the housing

Stress(Pa)	$1.224x10^{7}$(max)	449.2(min)
Deformation(m)	$1.1033x10^{-5}$(max)	0(min)
Factor of safety	6.6465	



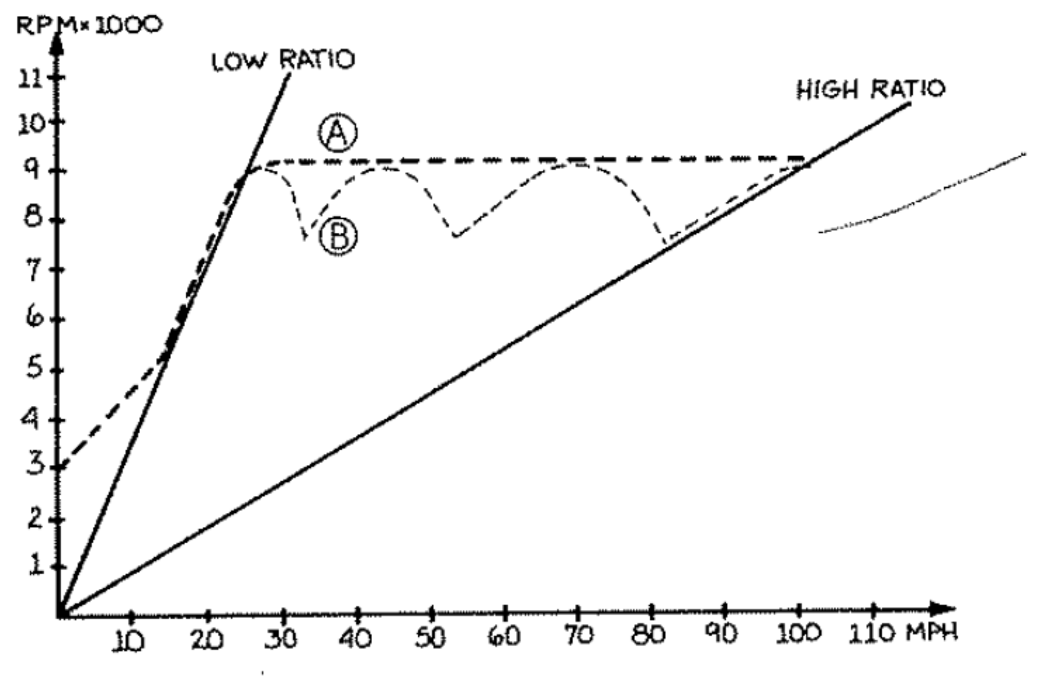
CVT

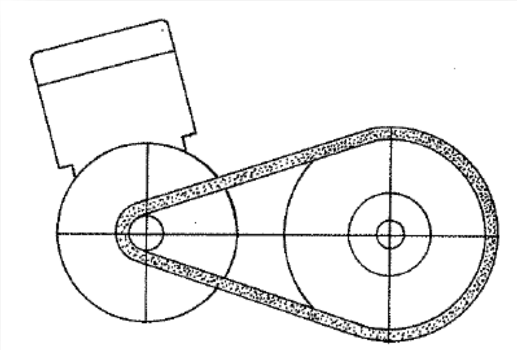
- <u>Engagement speed:</u>

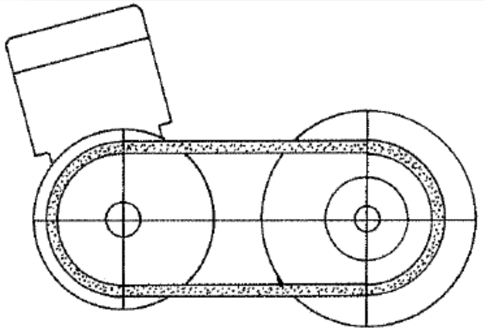
  The engagement speed is the RPM of the driver of the CVT at which the belt gets engaged with the sheaves to rotate the driven.

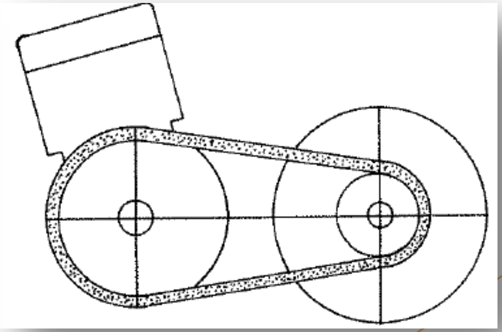
- <u>Shift speed:</u>

  The shift speed is the speed of the engine where the velocity ratio shifts from the lower ratio to the higher ratio.









Components of CVT

- <u>Driver/ Primary Clutch</u>

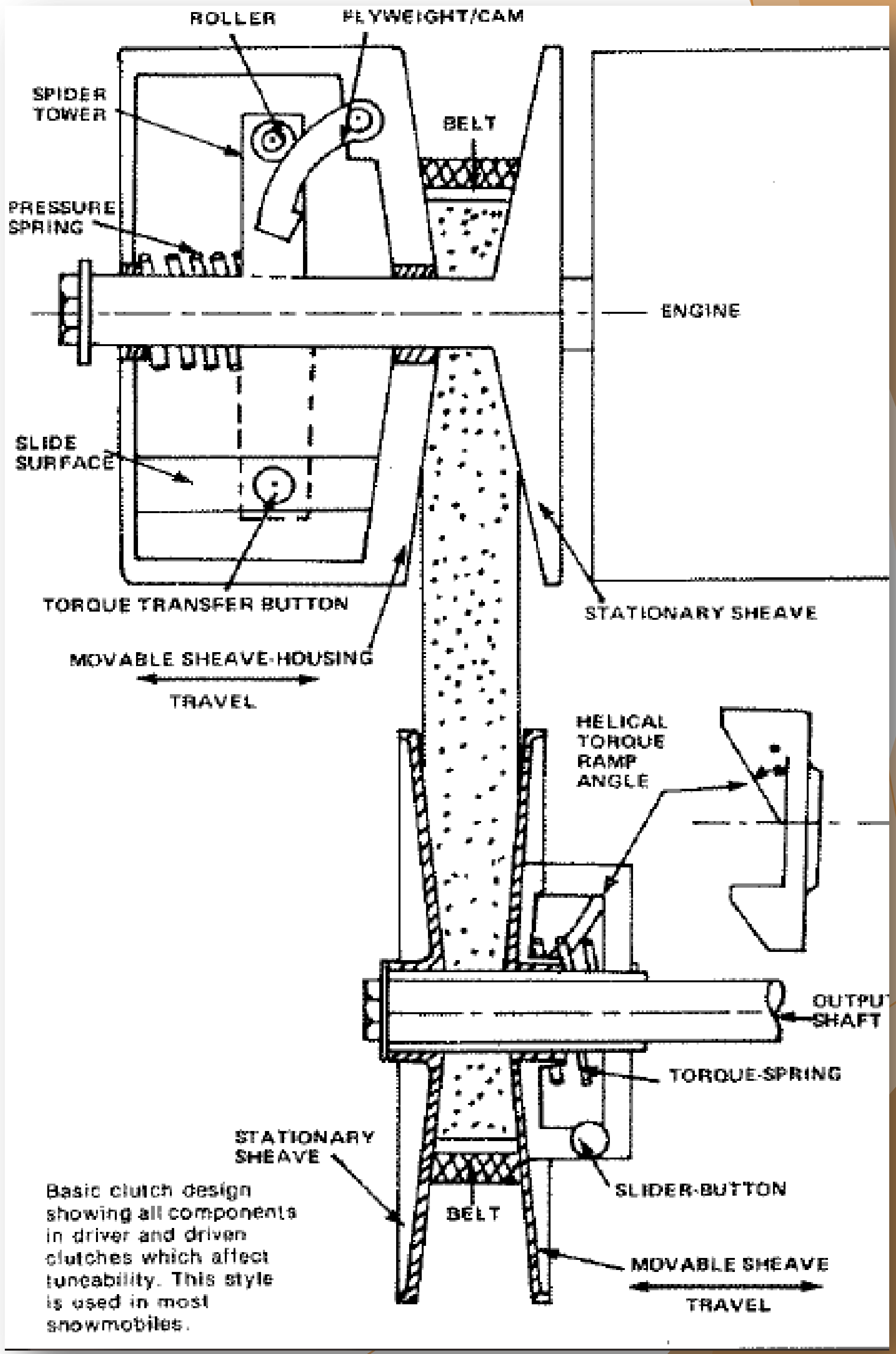
a. Pressure Spring: plays part in the engagement speed and in shifting from lower to higher gear ratio.

b. Flyweight Mechanism: utilizes centrifugal force to control engagement and shift speed.

- <u>Driven/ Secondary Clutch</u>

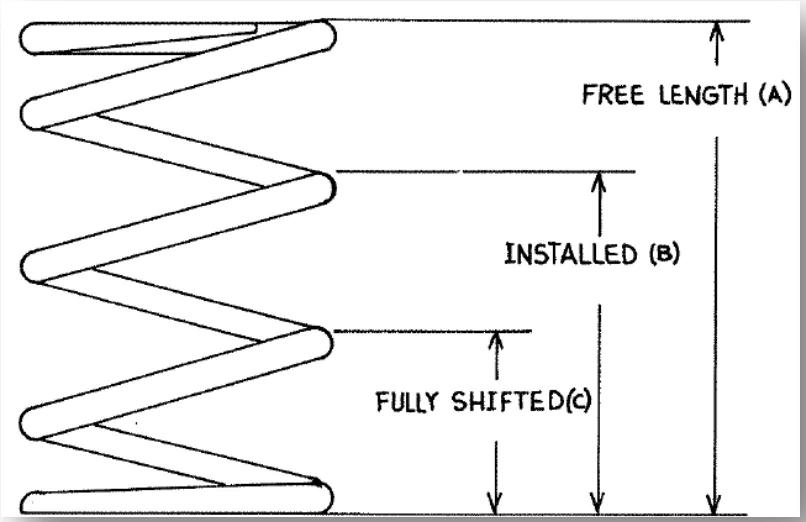
a. Pretension Spring: plays a role in initial belt pressure and back shifting.

b. Torque Feedback Ramp: determine the amount of side force that acts on the sheaves.

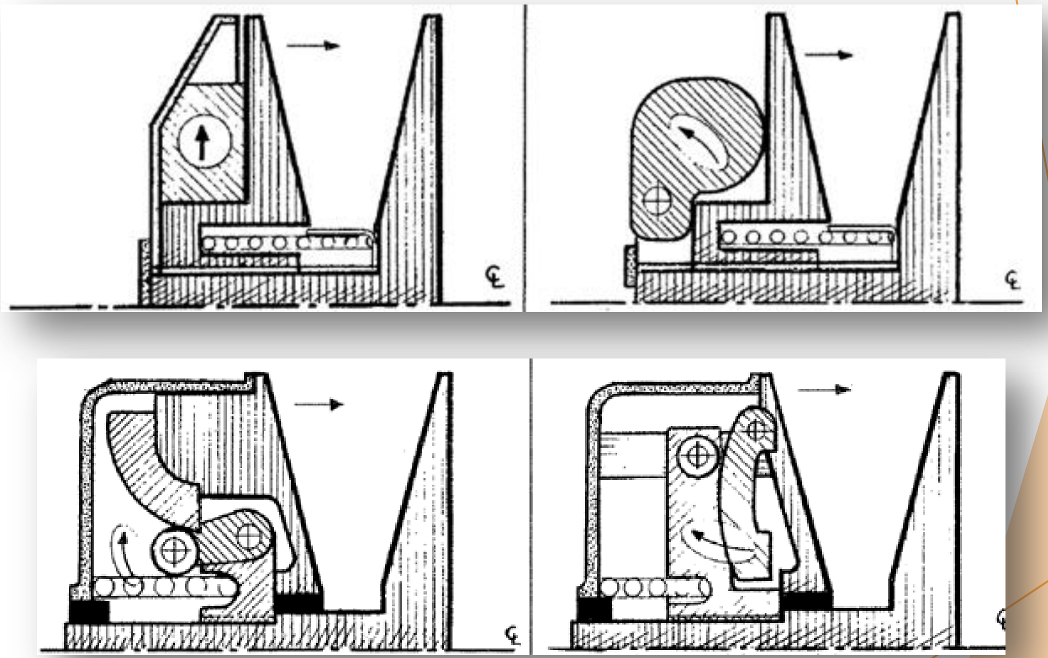


Driver/ Primary Clutch

1. <u>Pressure Spring</u>:

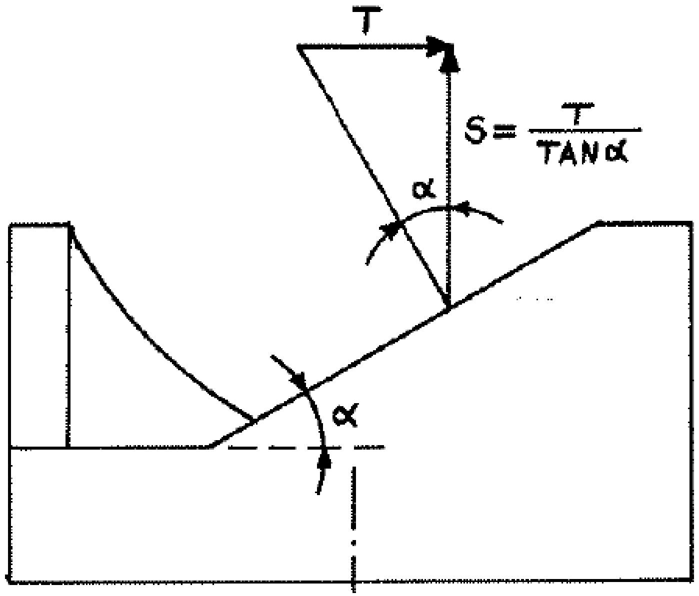


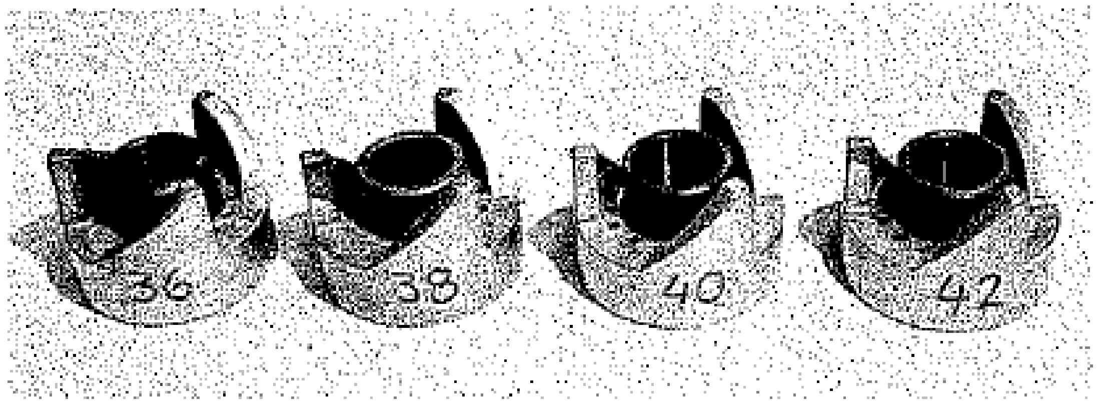
2. <u>Flyweight Mechanism</u>:



Driven/ Secondary Clutch

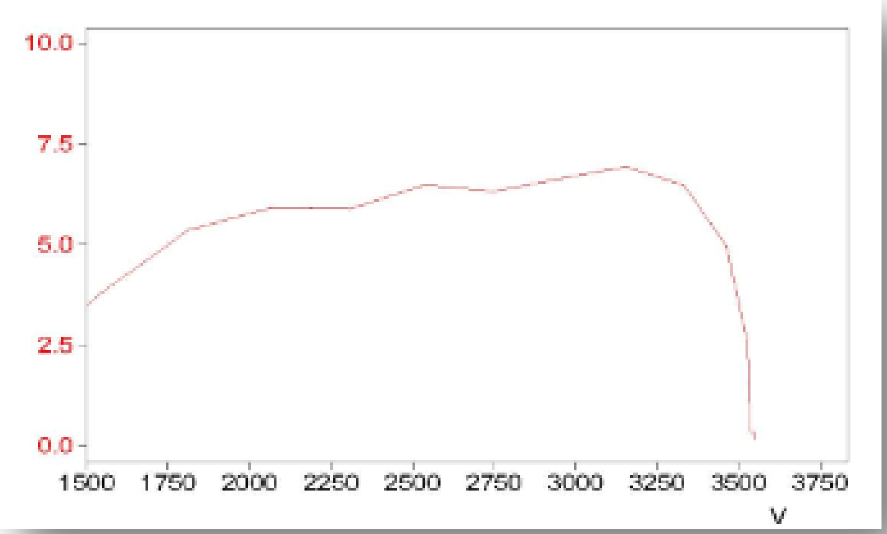
1. Pretension Spring:
2. Torque Feedback Ramp:

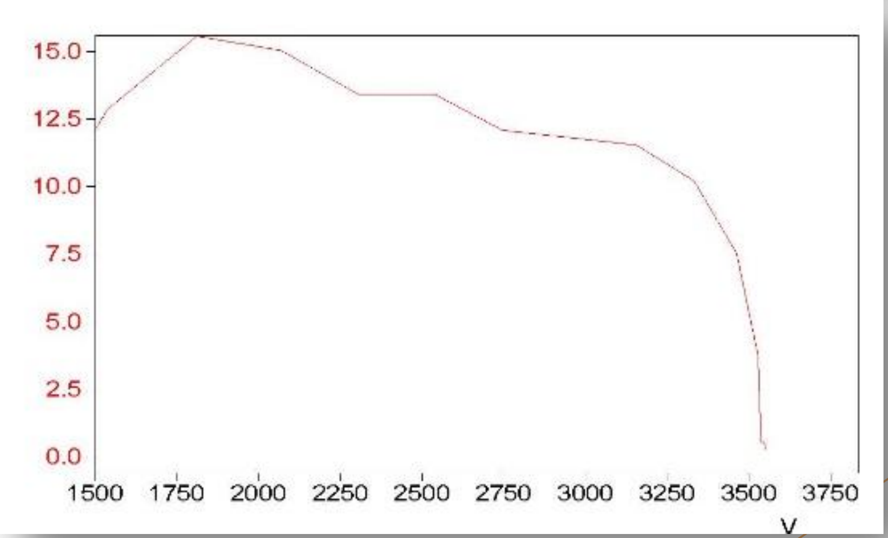




CVT tuning

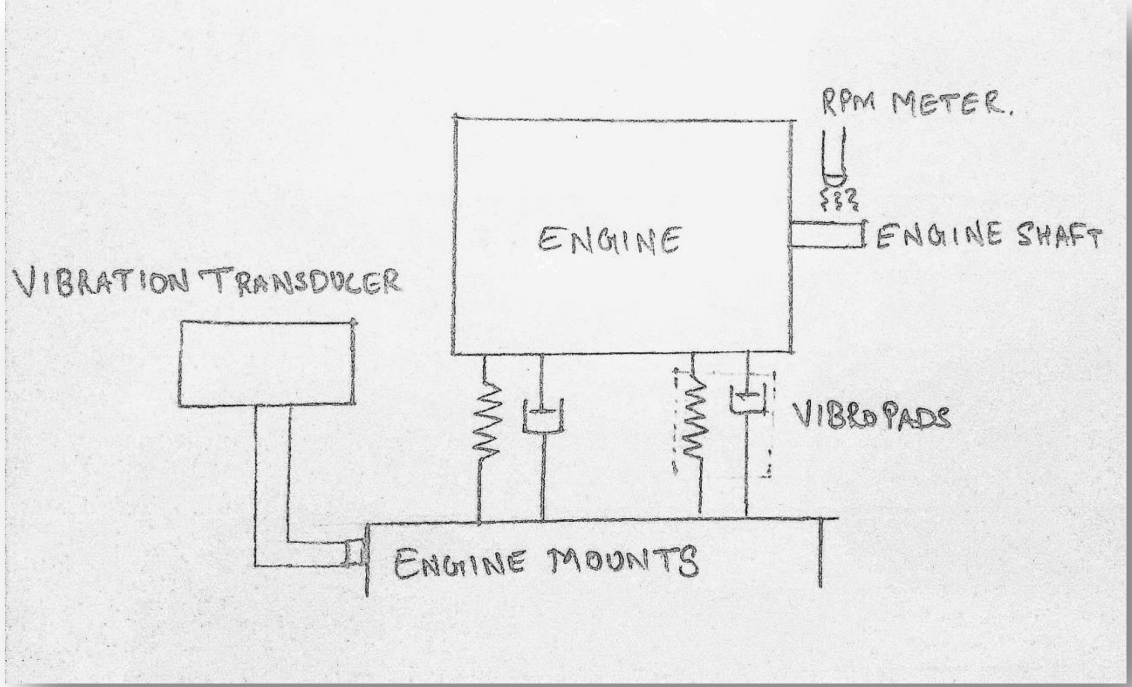
- Selecting the engagement rpm zone
- Selecting the shift rpm zone
- Selecting and playing with the weights and springs
- Selecting the optimum parameters
- Collecting data through testing
- Fine tuning for better acceleration and efficiency





Engine Vibration Analysis

- Aim of the experiment: To determine natural frequency of the engine using concepts of forced vibrations.
- Experimental Setup



Determination of Natural Frequency

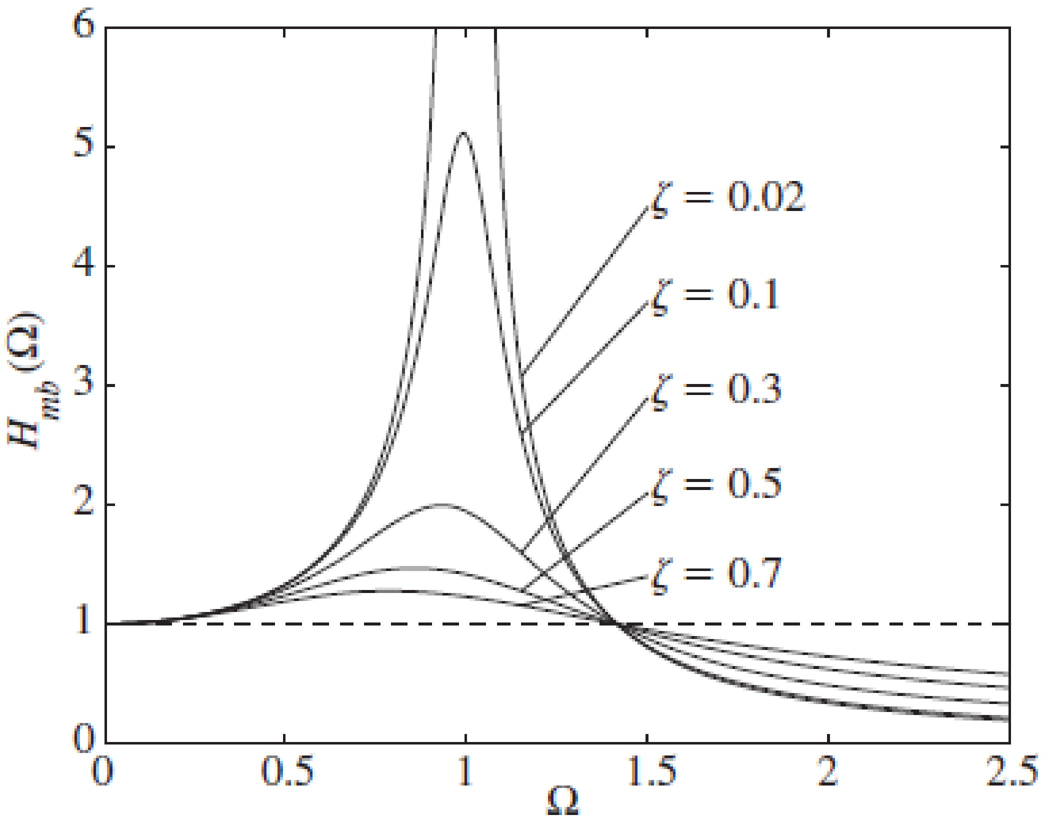
- From graph Ftr/Fo=1 at r=√2

Where r= frequency ratio = ϢϢ/ϢϢn

Ftr= Force transmitted to foundation

Fo= External Excitation Frequency (Mo*e*ϢϢ^2)

- Mo is the unbalance due to reciprocating piston of the engine



Determination of Unbalanced Mass

- From Engine specifications,

Bore Diameter (D) = 3.23in = 82.042mm

Stroke Length (L) = 2.28in = 57.912mm

Therefore Length of crank shaft (e) = L/2= 28.956mm

Mass of reciprocating parts (Mo)= Mass of piston + Mass of gudgeon pin
= 0.223 + 0.368 = 0.591 kg

- Reciprocating unbalance = Mo.e = 0.591*28.956

  = 0.0171 kg-m

- Thus from unbalance mass Mo.e, Excitation force Fo at various speeds can be calculated.

Experimental Permutations to find ωn

- The conditon of Ftr/Fo = 1 is obtained by trial and error method.
- This condition is achieved at speed ω = 2835 rpm
- At this conditon,
  Frequency ratio r = ω/ ωn= √2
  = 2835/ ωn = √2
  ωn = 2004.64 rpm
  =209.92 r/s
- Since the natural frequency of the system is 2004.64 rpm, resonance will occur at this point.
- The damping factor and damping coefficient of the mounts should be selected such that the engine is in isolation zone and should be able to sustain resonance condition.

Conclusion

- Through the study of previous designs, we came to the conclusion that the implementation of a differential is imperative, for the required maneuverability.
- Material research and property wise analysis helped us select Lm-6 series aluminum for the gearbox housing and EN-24 and EN-36 series for the gears.
- Through revised designs, we have achieved an FOS of a minimum of 6.64 at maximum stressed section.
- Permutations for CVT engagement and shift speed calculations provided us optimum values for the tuning parameters like flyweight values, spring loading and stiffness.
- After rigorous testing and enduring for about 70kms run, the entire transmission system is performing consistently with satisfactory results. It has sustained all types of rough and inclined gradients successfully.
- With suitable modifications the ATV has scope for application in various sectors such as military vehicle, for recreational sports and agricultural ploughing. They can also during natural calamities such as earthquakes to reach people who are inaccessible.

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